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Water Budget Analysis In Shallow Ground Water Regions Using Multiple Temporal Resolutions Data Sets

Sığ Yeraltı Sularında Çoklu Zamansal Çözünürlük Veriler Kullanılarak Su Bütçesi Analizi

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ABSTRACT

Amount of water in a catchment is major concern for both water supply and flood management in environmental systems. Water budget analysis gives an opportunity to represent and utilize hydrometeorological cycle, transport and storage of water in a basin. In this study, a water budget study that considers precipitation, river runoff, evapotranspiration, and ground water elevations for an urbanized watershed in the USA is presented. The urban basin, namely C11, is located in south-central Broward County, in South Florida in the USA. In this study, all the required data is obtained from the South Florida Water Management District's (SFWMD) hydrometerological database (DBHYDRO). Water budget results show that errors in the storage vary inversely proportional with increment in the temporal resolution. Annual water budget calculations provide the most consistent results that is approximately 10 percent of total out/in flow. Moreover, minor errors proofs that more proper results are captured during dry season months compared to one in wet season months.

Keywords: C11 Basin, Ground Water, Water Budget Analysis

ÖZET

Bir havzada bulunan su miktarı, su temini ve feyezan yönetimi için çevresel sistemler açısından önem arz eden iki konudur. Bu noktada, su bütçesi analizi havzalardaki suyun hidrometeorolojik döngüsü, taşınması ve depolanmasını temsil etme ve kullanmaya olanak sağlar. Bu çalışmada, ABD'nin Florida eyaletinde bulunan Güney Broward bölgesindeki kentsel bir havza olan C11 havzası kullanılmış olup, bu havza üzerindeki yağış, akarsu, evapotranspirasyon, yeraltı suyu verileri dikkate alınarak bir su bütçesi analizi sunulmuştur. Analizde kullanılan bütün veriler Güney Florida Su yönetimi Bölgesi (SFWMD) hidrometeorolojik veritabanından (DBHYDRO) elde edilmiştir. Sonuçlar depolama alanındaki hataların zamansal çözünürlükteki artışla ters orantılı olarak değiştiğini göstermektedir. Elde edilen veriler, yıllık su bütçesi analiziyle en tutarlı sonuçların elde edildiğini ve yaklaşık olarak toplam akışın yüzde 10' una karşılık geldiğini göstermektedir. Ayrıca, az yağış alan sezondaki hataların diğer aylara kıyasla daha uygun olduğu gözlemlenmiştir.

Anahtar Kelimeler: C11 Havzası, Su Bütçesi Analizi, Yeraltı suyu

1. INTRODUCTION

While controlling water facilitates human life in terms of water resources, dominance of water over people may provoke to catastrophic consequences such as lack of water supply and flooding issues. According to the fact that Earth's majority water is saline and is found in the oceans with the small percentage freshwater (2,5% of global water). Thus, only a relatively its small amount is available to sustain human, plant, and animal life (USGS, 2017). Industrial and economical developments and population growth have impacted the capacity of water resources to meet demands in especially arid countries (Gonzalez, 2016), at the same time too much water can lead flooding, in some cases over sub-tropical environment (Diş and Anagnostou, 2016). Therefore, it is important to know the amount of water for available supply and for preventing flooding issues in a watershed. In this research, an urbanized basin located in south-central Broward County, in the South Florida is studied to understand aforementioned situations and watershed characteristics.

The catchment in South Florida has two distinctive precipitation periods. Wet season starts in June and continues through October, while dry season is from December to April. The months of May and November are considered transition months in the area (Skinner et al., 2009). The population of the Broward County has grown rapidly since 1985. Hence, water supply and flood management are major issue in this highly urbanized area (Diş, 2011). South Florida Water Management District (SFWMD) is responsible to manage water resources in terms of both quality and quantity. In the region numerous district's manmade channels and control structures serve to keep water when it is in the dry season, and to protect the area against flood in the wet season (Skinner et al., 2009).

The amount of direct runoff is considered as a major concern for flood management and storm events in the catchment are associated with high variability and unique basin flood response characteristics (Diş, 2011). Therefore, excess water must be discharged from the area before the flooding occurs during wet season. On the other hand, since the region is highly urbanized with intensive settlements, control structures needs to keep water when it is in the dry season. These important extreme situations and associated hydrological parameters such as precipitation, evapotranspiration, groundwater, and in/out direct runoff are analyzed. The primary focus of this study, therefore, is to determine the volume of available water for water supply in this complex system and the detect flooding in the C11 basin using different temporal resolution datasets.

2. STUDY AREA

The South Florida Water Management District (SFWMD) is one of five government agencies responsible for the oversight and protection of water resources in the state of Florida (Skinner et al., 2009). Since 1949, the District has been serving to manage and protect water resources of the region by balancing and improving water quality, flood control, natural systems and water supply. The SFWMD service area extends 16 counties from Orlando to Florida Keys and serves a population of 7.5 million (SFWMD,2017). DBHYDRO is the District's hydrometerological database and provides water quality, and hydrogeologic data storage and retrieval system (DBHYDRO,2017).

The study area, namely C11 basin, which covers approximately 97 (251,23 km^2) square miles is located in south-central Broward County, in Florida (Figure 1). The basin consists of two basins: C11 East (27% of total area) and C11 West (73% of total area) basins. In the C11 basin, canals and control structures are served for four main reasons. Firstly, they provide flood protection and drainage for the basin; secondly, one of their purpose is water supply during low natural flow periods, additional to controlling and intercepting seepage from Everglades (WCA3A). Lastly, they maintain a ground water table elevation west of S13 adequate to prevent saltwater intrusion into local groundwater (Diş, 2011).

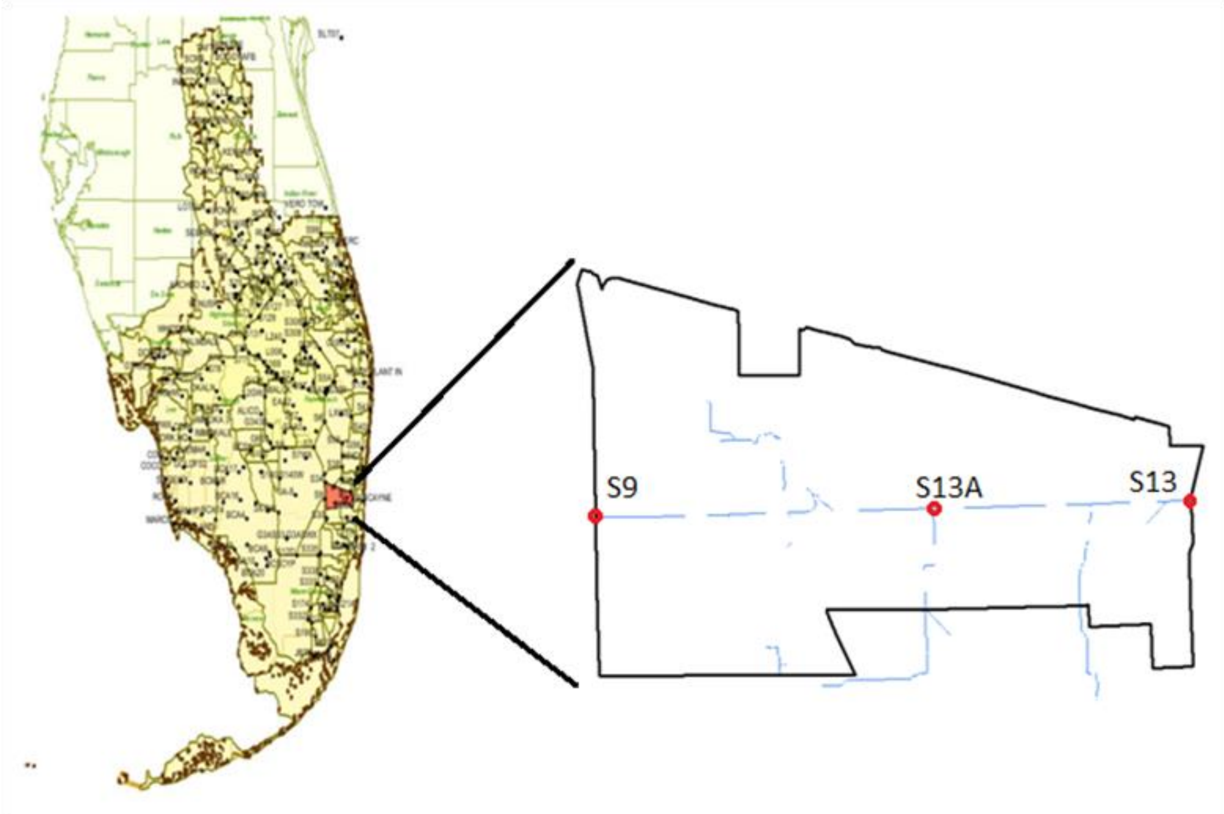

Figure 1. Location of C11 East and West basins in the SFWMD area

Plenty of control structures (pumps, spillways, and culverts) are serving in the catchment and some of the them are more critical due to the location and intended use: S9, S9A and S13, S13A, S381 structures. These three (S9, S9A and S13) of them are located in the catchment border and work as an outlet point for the basin. The other two are serving to separate seepage from the canal and which in adjusting the desired water level (Diş, 2011; Diş and Anagnostou, 2016).

S9 is a pumping station located in the western boundary of C11. The primary principle of this structure is pumping excess water in the C11 to Everglades (WCA3A). S9A structure has been effective for nine years to energy efficiency with the same purpose of S9 station. The use of S9A reduces the operational dependency placed on the larger S9 pumping station (Figure 2). S13 structure, on the other hand, has three pumping units and one gated spillway that control flows that bypass the pumps which is located at the eastern boundary of the basin (Figure3). The other one named as S13A culvert station that discharge additional excess water from west part to eastern basin. S381 spillway divided primary canal into two parts and direction of flow of west of S381 is to west; in western part, water is discharged into Everglades (WCA3A). However, east of S381, water is going to east and discharged by S13 structure (Figure 4). The primary canals within the basin are C11 and C11S Canals; C11 Canal is aligned east-west parallel. When constructed in the 1950s, this canal’s main function was preventing flooding during wet season and ensuring available water during dry season. The direction of flow western basin depends on the operation of control structures S13A, S9, and S9A structures. On the other hand, the direction of eastern basin is to east with discharge to South Fork of New River by S13 structure. C11S Canal bisects western side of the basin in an north-south direction. Flow direction of the structure is from north to south and stream makes an open channel connection with C11 Canal (Diş and Anagnostou, 2016).

Figure 2. S9 pump station that discharges urban and agricultural storm water runoff from the C11 Western side in Broward County directly into WCA3A (Diş, 2011)

Figure 3. The S13 pump structure (Diş, 2011)

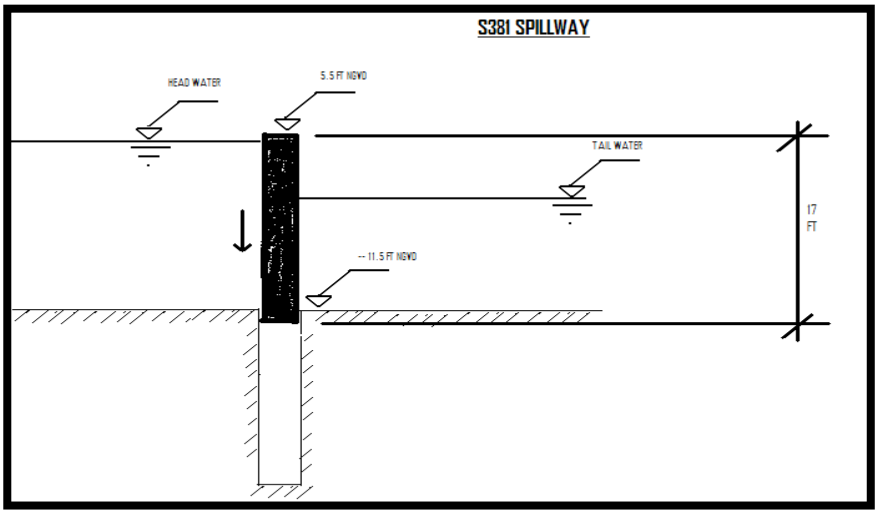

Figure 4. S381 spillway structure

3. DATA AND ANALYSIS

3.1. Data

All the required data, in this study, is acquired for the period between May 1 2007 and April 30 2008 using the District's hydrometerological database (DBHYDRO) which is a data browser in the District's website. DBHDRO helps users to obtain hydrometeorologic, hydrogeologic, and water quality data. It is not only easy for downloading data, but also it is convenient to reach important information for each station with a given Data Base Key (DBKEY). The browser provides essential catchment characteristics, description of the structures, information regarding to hydrological data sets and many other environmental data for the South-Florida region. In figure 5, an example view is shown from DBHYRO browser related to these useful data sets.

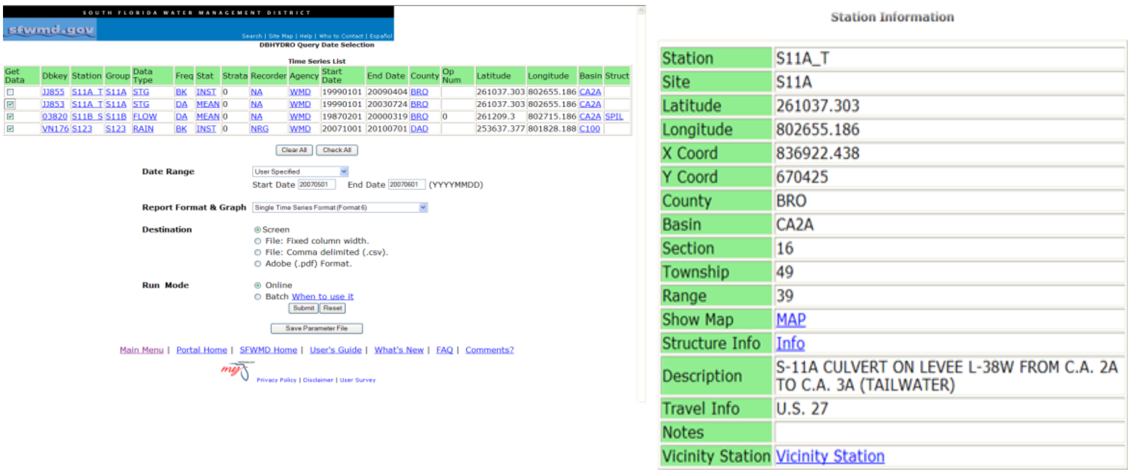

Figure 5. Example view from DBHYRO data browser

In Florida, rainfall occurs all around the year, but rainfall amounts vary significantly in space and time; specifically, the amount of rainfall is higher over the southern part of the State versus the north. Two distinct rainfall periods are observed in South Florida due to seasonal variations in precipitation patterns: wet and dry. The wet season lasts from June to October where rainfall occurs from high intensity and short duration convective storms, including severe thunderstorms. Roughly two thirds of the annual rainfall received at the SFWMD occurs during the wet season. The dry season, on the other hand, is in effect from December to April, where rainfall occurs from low intensity and long duration storms; frontal systems are the main meteorological causes of rainfall during this season. Lastly, May and November months are transition months where mixture of convective and frontal systems may occur (Skinner et al., 2009; Diş, 2011). Rainfall data in SFWMD are available from rain gauge, NEXRAD, and gauge-adjusted NEXRAD rainfall products. These three rain gauges are S9R (C11 West), FT.LAUD.(Fort Lauderdale)R, and S13R (C11 East). Aforementioned three types of data are available in DYBHYDRO data browser (DBHDRO,2017). However, Huebner et. al. (2003) claim that rain gauges alone may not provide enough spatial rainfall distributions for use in hydrological applications due to wind, obstructions, evaporation loss, wetting loss, and instrument errors. In addition, Pathak (2008) states that rain gauges can miss to record tropical and convective rainfall events in the South Florida region. According to Bedient et al. (2000), gauge adjusted NEXRAD radar data can produce precise quantitative rainfall estimates comparing to rain gauge data alone. The most reliable data sets, therefore, gauge-adjusted NEXRAD that allow water managers to accurately track spatial and temporal variations of rainfall is used in this study.

Potential evapotranspiration (PET) data is obtained also from the SFWMD's website, DBYHDRO. Pathak (2008) mentions numerous of methods for estimation of actual evapotranspiration (ET) by applying crop or vegetation coefficients to the PET and he lists some of them as: Penman, Corrected Penman, and Penman-Monteith. He claims that the district developed historical and currently daily PET datasets for wetlands using "the Simple Method. Additionally, four ground water wells, as shown in the figure 6, are located in the basin; two of them located in the western side (G617 and G2034) and the other two are in the eastern side (G1221 and G1223). Ground water direction was decided based on the depth elevations based on the ground water depth time series (Figure 6). During most of the period, ground water direction is from G617 to G2034 in the western side. However, the direction is from G1223 to G1221 in eastern side. In addition, other well data, which are located close to the C11 Basin, was also obtained to see ground water direction more clearly.

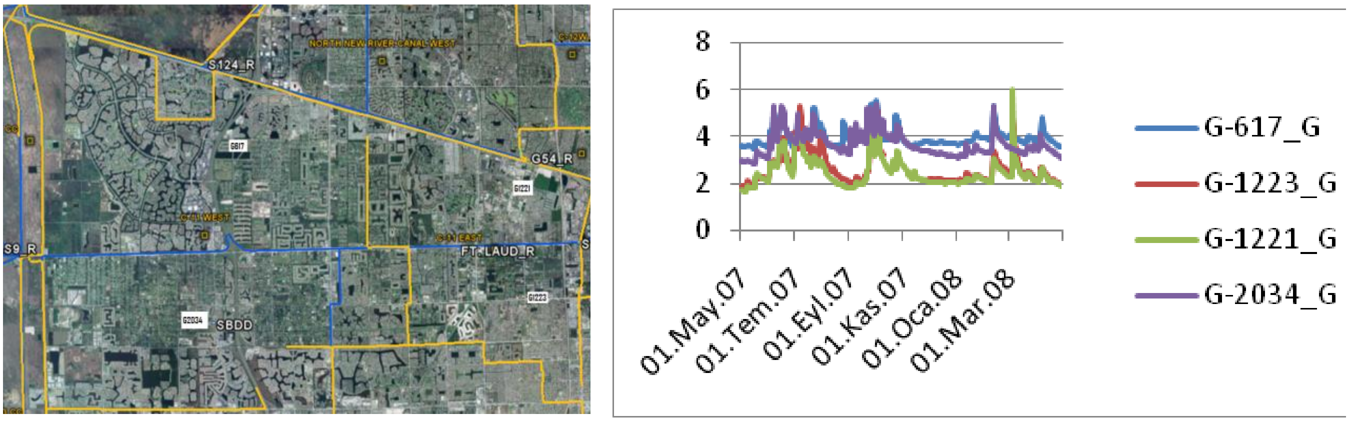

Figure 6. Location of rain gauges and ground water well stations, and its plot over one year time period (01.05.2007-30.04.2008)

3.2. Water Budget Analysis

One year water budget was conducted to see which parameter (ground water, rainfall, evapotranspiration etc.) is most effective in the basin. Figure 7 represents water budget cycle on the ground which is dealt with in water budget. For this calculation basically the difference between total inflow and total outflow should equal to zero; more accurately water budget equation can be expressed as with equation 1:

$$\frac{\Delta S}{\Delta t} = (I - O) + P - ET \pm GW \pm £ \quad \textbf{(1)}$$

where abbreviations explained as following:

$\frac{\Delta S}{}$	:	Change in storage over time
£	:	Error
I	:	Inflow
O	:	Outflow
P	:	Precipitation
ET	:	Evapotranspiration
GW	:	Ground water

Table 1a shows the total in/outflow parameters taking into account in the analysis for C11 East Basin and for the west part is illustrated 1b, respectively. When we contacted to operator employee in the district, S381 structure was built for seepage separation between WC3A and C11 Basins. Therefore, an assumption needs to be considered that flow direction west of S381 east to west direction and S9 and S9A pump structures are using for discharge all time for western boundary. In addition, direction of flow for eastern part of S381 structure is always west to east and S13A structure discharging water from eastern boundary of C11 East Basin. On the other hand, S13A structure is inflow for C11 East Basin because of this assumption. Regarding to precipitation and increment in the ground water change aspects considered as inflow for both catchments. However, decrement in the ground water change and evapotranspiration counted as outflow.

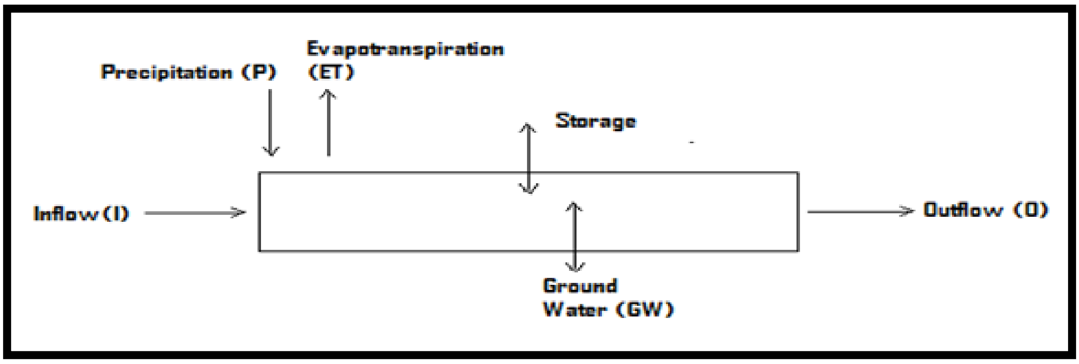

Figure 7. Water budget cycle on the ground

Table 1a. Total in/outflow parameters for C11 East Basin

Total Inflow	Total Outflow
S13A Structure	S13 Structure
Rainfall	ET
GW_{in}	GW_{out}

Table 1b. Total in/outflow parameters for C11 West Basin

Total Inflow	Total Outflow
	S13A, S9, S9A Structures
Rainfall	ET
GW_{in}	GW_{out}

Change in depth of storage was assumed that equals into the canal depth change. In other words, increment/decrement in the canal elevation is the same as storage change. After this assumption topographic data obtained as table 2. According to this, area based on each surface elevation is known. Then, volume was calculated and plotted versus elevation between 0-12 feet. Here after, volume can calculate based on given elevation, and volumetric variation plotted against to the elevation change in the watershed (Figure 8). In C11 East (West) Basin average elevation change was calculated in the canal and storage volume change using equation 2 (equation 3). H and T represent head and tail water, respectively and the structures names are given as subscript in the equations. Then, change in the storage for the eastern (western) side, $\Delta S_{E(W)}$, calculated with following equation 4(applying the plot in figure 8).

Table 2. Elevation change versus area

Elevation	Area	Elevation Range	Volume
[FT]	*[ACRE]*	*[FT]*	*[ACRE-FT]*
-2	39		
0	1463	(-2)-0	1502
2	5514	0-2	6978
4	16170	2-4	21685
6	40920	4-6	57090
8	59052	6-8	99972
10	62133	8-10	121185
12	62980	10-12	125113

$$x_E = {\Delta(H_{S13} + T_{S13A})}/{2} \qquad \textbf{(2)}$$

$$x_W = {\Delta(H_{S13A} + T_{S381} + H_{S381} + H_{13A})}/{4} \qquad \textbf{(3)}$$

$$\Delta S_i = 0{,}883x_i^{\,6} - 24{,}207x_i^{\,5} + 190{,}27x_i^{\,4} - 259{,}42x_i^{\,3} - 150{,}3x_i^{\,2} + 2913\,x_i + 1502{,}2 \qquad \textbf{(4)}$$

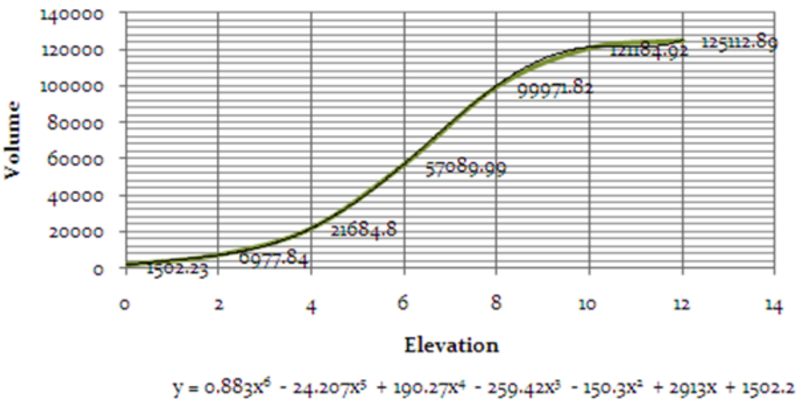

Figure 8. Volumetric variation according to elevation change

4. DISCUSSIONS AND CONCLUSIONS

This water budget is carried out based on daily, monthly and annual for two basins in C11 East and West separately. Water year runs from May 1st 2007 to April 30th 2008, and water budget accounted for inflow, outflow, precipitation, evapotranspiration, and errors. For example, daily errors were plotted in percent of outflow and inflow and in acre-feet versus number of the days. Figure 9a, the first column, illustrates the daily error for the C11 East Basin, and the error is between ±3000 percent; in addition second column, figure 9b, represents the daily error for the C11 West Basin and the error is less than western side between -200 to +1000 percent, but fluctuation is high comparing to eastern side.

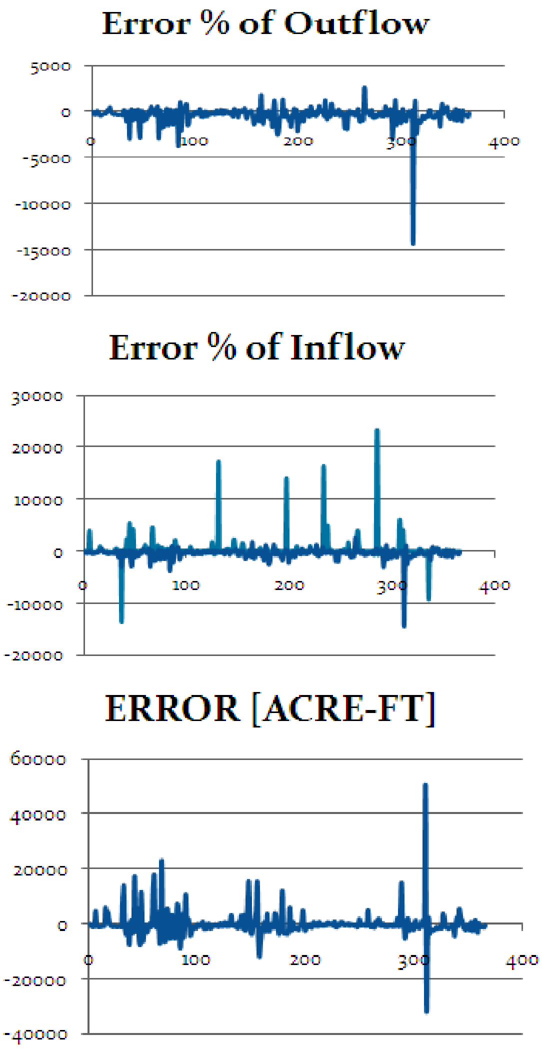

Figure 9a. Daily error for C11 East Basin

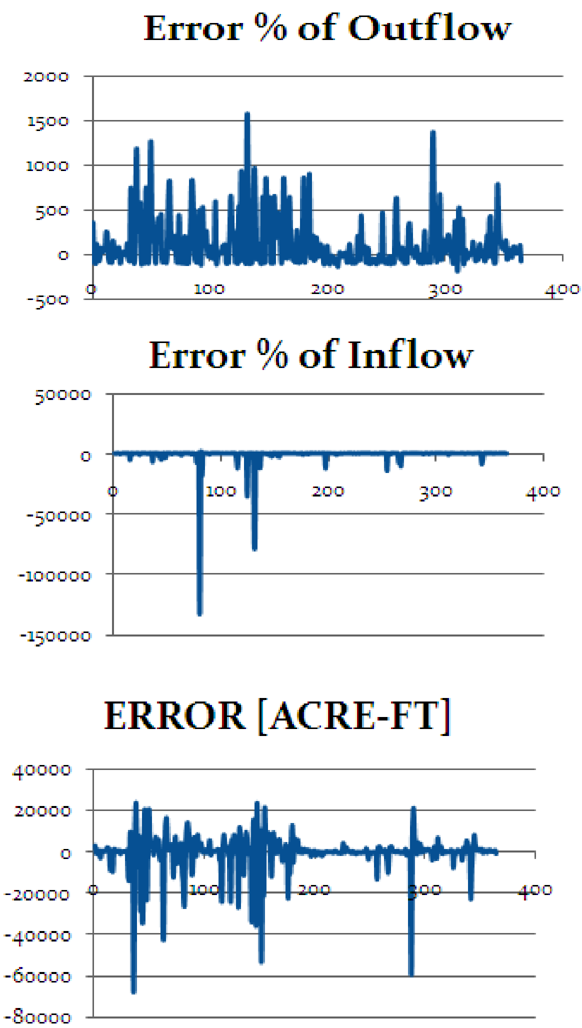

Figure 9b. Daily error for C11 West Basin

After looking at daily water budget errors, monthly and annual errors were calculated. Results prove that monthly errors are more consistent than daily error values. For instance, table 3 shows the errors in C11 East Basin and the values are between -53 and 84 % of total inflow. On the other hand, annual water budget calculations gave the best result, likely expected, it is approximately 10 percent of total out/in flow. Similar results were also gotten for C11 West Basin (Table 4) . In addition, it is observed that monthly errors in wet season is higher compared to one in the dry seasons.

Table 3. Errors in C11 East Basin

Time Period	**Error**	**Inflow Error**	**Outflow Error**
	[ACRE-FT]	*[%]*	*[%]*
May-07	-7081	-53,9	-34,9
Jun-07	-19332	-32,7	-25,9
Jul-07	29969	35,9	54,7
Aug-07	25437	73,8	247,9
Sep-07	-21423	-64,8	-43,5
Oct-07	10902	15,2	18,8
Nov-07	17331	84,4	142,4
Dec-07	1527	37,6	38,2
Jan-08	-1908	-17,8	-14,3
Feb-08	-134	-0,5	-0,6
Mar-08	3990	6,0	6,4
Apr-08	2058	9,7	11,4
Annual	**41336**	**9,3**	**10,3**

Table 4. Errors in C11 West Basin

Time Period	**Error**	**Inflow Error**	**Outflow Error**
	[ACRE-FT]	*[%]*	*[%]*
May-07	-12968	-37,9	-26,9
Jun-07	-34217	-16,4	-14,1
Jul-07	-33175	-21,6	-17,8
Aug-07	12918	15,7	18,8
Sep-07	-87684	-55,9	-35,7
Oct-07	33843	20,5	26,6
Nov-07	3949	15,2	15,6
Dec-07	3549	15,3	17,8
Jan-08	-22205	-83,4	-45,4
Feb-08	-6793	-7,0	-6,6
Mar-08	-6281	-13,6	-12,3
Apr-08	950	1,4	1,4
Annual	**-148114**	**-13,6**	**-11,9**

Water budget analysis is convenient for large river basin water supply, flood hydrology to small urban or natural watershed problems. It can be also considered as preliminary analysis before any rainfall-runoff simulations to see effective hydrological parameter in a basin. Additionally, it may help to understand with(out) other software for a lot of studies, such as, water availability, urban drainage, and flow forecasting future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and system operations. In this study, therefore, water budget analysis is carried out for different temporal resolution to understand how an urbanized basin, C11, characterized with the hydrological parameters in sub-tropical environment.

Water budget was run for one year period in the C11 Watershed. Outcome of this study show that even though annual water budget represent storage change in the basin, errors related to 15 min data sets illustrate unreasonable results. Errors vary with temporal resolution as: ε(15min)>ε(Daily) >ε(weekly) >ε(monthly) >ε(annual). Moreover, this application depict that, during dry period, results are more accurate compared to wet period months.

5. REFERENCES

Bedient, P.B., Hoblit, B.C., Gladwell, D.C. and Vieux, B.E. (2000). NEXRAD Radar for Flood Prediction in Houston. *Journal of Hydrologic Engineering*, July, Vol.5 (3), pp. 269-277.

DBHYDRO (2017). DBHYDRO Browser User's Guide. *South Florida Water Management District*, April (revised).

Diş M.Ö. (2011). Hydrological Analysis of an Urban Basin in Sub-Tropical Environment. Master Theses. University of Connecticut. 90p.

Diş, M.Ö. and Anagnastou, E. N. (2016). Hydrological Analysis of an Urban Basin in Sub-Tropical Environment. *12th International Congress on Advances in Civil Engineering*, 21-23 September Istanbul, Turkey. 8p.

Gonzalez, R., Ouarda, T.B.M.J., Marpu, P.R., Allam, M.M., Eltahir, E.A.B., Pearson, S. (2016). Water Budget Analysis in Arid Regions, Application to the United Arab Emirates. *Water.*September, 8(9),415.

Huebner, R.S., C.S. Pathak and B.C. Hoblit (2003). Development and Use of a NEXRAD Database for Water Management in South Florida. *ASCE World Water & Environmental Resources Congress*, June 23-26, Philadelphia, Pennsylvania, USA.

Pathak, C.S. (2008).Hydrologic Monitoring Network of the South Florida Water Management District. South Florida Environmental Report, *South Florida Water Management District*, West Palm Beach, Florida, USA, Volume I, Appendix 2-1.

Skinner, Courtney, Bloetscher, Frederick, and Pathak, Chandra S. (2009). Comparison of NEXRAD and Rain Gauge Precipitation Measurements in South Florida. *Journal of Hydologic Engineering ASCE*. Mar.: 248-260

South Florida Water Management District (SFWMD)-Data Browser: URL (Access Date: 16.08.2017) http://www.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu

USGS. URL (Access Date: 25.08.2017) https://water.usgs.gov/edu/earthwherewater.html